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LONG-TERM TESTS OF Cu_2S-CdS THIN-FILM SOLOR CELLS UNDER SIMULATED ORBITAL CONDITIONS

by J. J. Smithrick
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

and

D. R. Clarke
The Boeing Company
Seattle, Washington

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ABSTRACT

Cu_2S-CdS thin-film solar cells have been tested under simulated orbital conditions at The Boeing Company under contract with the NASA-Lewis Research Center. In a recent test, cells have been thermally cycled for 10,050 cycles by illuminating them with a xenon-arc solar simulator for one hour and allowing them to cool in the dark for a half hour. This is the longest thermal cycling test of Cu_2S-CdS solar cells to date. In another chamber cells have been continuously illuminated for 6660 hours by a xenon-arc solar simulator. During both tests data were taken periodically to monitor the performance of the cells.

In this report the test facilities are described. Results of long-term thermal cycling and continuous illumination tests are presented. One of the more important difficulties encountered with the temperature is also discussed.

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IN NEAR EARTH ORBIT MISSIONS Cu_2S-CdS thin-film solar cells will be subjected to alternate periods of illumination and darkness. In other space missions, the cells will be subjected to continuous illumination. As a part of a continuous evaluation program of Cu_2S-CdS solar cells, The Boeing Company, under contract with the NASA Lewis Research Center (1)*, is conducting tests on cells under both of the orbital conditions described above. The cells are being tested in two vacuum chambers. In one chamber the cells are being thermally cycled by illuminating them with a xenon-arc solar simulator for one hour and allowing them to cool in the dark for a half hour.

In the other chamber, cells are being continuously illuminated by a xenon-arc solar simulator. During the test, data are taken periodically to monitor the performance of the cells.

All cells being tested in this evaluation program were manufactured by Gould, Inc. (formerly Clevite Corporation) (2). They are nominally 7.5 cm x 7.5 cm in size with a Kapton plastic substrate and cover. Total cell thickness is about 0.01 cm.

The material covered in this report includes a description of the facilities, results of thermal cycling and constant illumination tests of thin-film solar cells, and a temperature problem which was encountered.

TEST FACILITIES

Cu_2S-CdS solar cells were tested in two similar facilities at The Boeing Company. In figure 1 a schematic of one facility is shown. The test facility consisted of a vacuum chamber, solar simulator light source and a temperature control block.

The vacuum chamber was composed of a stainless steel shell, cold shroud, a quartz window, a supporting bracket for the test cell mounting frame and vacuum pumps. The shroud was painted black and cooled with liquid nitrogen to simulate a space heat sink. A mechanical roughing pump and an ion pump were used to provide the vacuum. The roughing pump brought the chamber pressure down to 10^{-4} torr, after which the ion pump was started and the roughing pump was removed. The ion pump maintained a pressure of 10^{-8} torr or less when the shroud was cooled with liquid nitrogen.

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*Numbers in parentheses designate References at end of paper.

Radiant heaters were mounted 1-1/2 inches behind the cells to maintain a constant cell temperature during the test. These heaters consisted of tantalum wires mounted in a frame. Current through the wires was adjusted to maintain constant cell temperature.

The xenon-arc solar simulator light source was mounted on a pivoted platform so that it could be used to illuminate the cells located in the vacuum chamber, or rotated to illuminate a Cu_2S-CdS standard cell located on the temperature control block outside the chamber. The water cooled shutter, located between the solar simulator and the quartz window was used to interrupt the light beam when the solar cells were to be in the dark.

PROCEDURE

A thermal cycle consisted of illuminating the solar cells for one hour with the xenon arc light source and then interrupting the lamp beam with the shutter and allowing the cells to cool in the dark for a half hour. During the illumination portion of the cycle the initial cell equilibrium temperature was 60° C and during the dark portion of the cycle the temperature reached -110° C. The 60° C temperature was selected to simulate the temperature of the cells in near Earth orbit. The temperature of each cell was measured with a copper-constantan thermocouple. The thermocouples were attached to the back of some cells with masking tape and to others with Al tape. The Al tape was painted black. The thermocouples which were attached with masking tape eventually came loose, due to relaxation of the tape. The masking tape was replaced by aluminum tape, which kept the thermocouples in good contact with the cells. Each thermocouple was coated with a silicon heat sink compound to insure good thermal contact to the cells. After a temperature difficulty was observed during the thermal cycling test the radiant heaters were used to maintain a constant cell temperature. This temperature difficulty will be discussed under results and discussion. During the continuous illumination test the cells were also illuminated with a xenon-arc light source. The equilibrium temperature of these cells was 55° C, which corresponded to the calculated temperature of the cells in a synchronous orbit. This temperature of 55° C was maintained from the start of the test using radiant heaters.

During both the thermal cycling and continuous illumination tests each individual cell was loaded at its initial maximum power point with a fixed resistance across its terminals. The performance of the cells was computed from the voltage drop measured periodically across the fixed resistance. Before taking a performance measurement the solar simulator intensity was set to air mass zero (AMO) intensity with an airplane flown Cu_2S-CdS standard cell (3) which was located on the temperature control block.

Before and after these long term tests the power output of each cell was measured on the temperature control block outside the chamber.

RESULTS AND DISCUSSION

The manufacturing date of the solar cells recently tested at The Boeing Company are presented in table 1. The initial efficiencies of these cells are presented in table 2.

THERMAL CYCLING TEST - In chamber 1 a total of nine individual cells were thermally cycled. Four of the cells were manufactured in November 1968 and five in June 1969. The results for the November 1968 cells are shown in figure 2. The in situ relative power (relative to cycle 1) is shown as a function of thermal cycles for the best (or least degraded) and the worst (most degraded) cell of the group. These cells were exposed to 10,050 cycles, the longest thermal cycling test of Cu_2S-CdS cells to date. The best cell degraded only 9 percent and the worst degraded 24 percent. The average degradation of the four cells was 18 percent.

In table 2 the agreement between the in situ and control block relative powers is good, being within an average of three percent. The differences seen between the in situ and control block data are presumably due to the effects of the atmosphere on cell performance.

Figure 3 shows the in situ relative power as a function of thermal cycles for the best and worst of the five June 1969 cells. After 7926 cycles the best degraded only 11 percent and the worst 31 percent. The average degradation of the five cells was 23 percent.

In table 2 a large discrepancy in the degradation measured in situ and on the control block is seen for cell nine. The cause is unknown. If this cell were omitted, then the rest of the June 1969 cells agree to three percent on the average.

The degradation of the June 1969 cells is greater than the November 1968 cells. This greater degradation is probably due to cell vintage.

In figure 4 the recent long-term thermal cycling data for the November 1968 cells are compared to the results of an earlier test on cells manufactured in October 1967. The cells tested recently degraded less severely in power output than cells tested earlier. The recovery in the October 1967 cells occurred when the test was interrupted. This greater degradation is believed to be due primarily to excessive load voltage, although cell vintage may have been a contributing factor. In earlier tests the importance of load voltage was not recognized and the cells were probably loaded beyond the decomposition voltage of Cu_2S (4) which resulted in greater degradation. In the recent test all cells were loaded at their initial maximum power voltage which is below the decomposition voltage of Cu_2S. The relatively slow degradation seen in recent tests is believed due to a different, but yet unknown mechanism.

CONTINUOUS ILLUMINATION TEST - In chamber 2 three individual cells and six cells in a series string were tested. These cells were all manufactured in September 1969. The cells were thermally cycled for 227 cycles and then were continuously illuminated thereafter. In figure 5 the in situ relative power of the best and worst cell of the individual cells is shown. After 6660 hours the best degraded 16 percent and the worst degraded 23 percent. The average degradation of the three cells was 21 percent.

In table 2 the large discrepancy for cell 12 is unknown. If this cell is dropped, the average of the remaining two cells agrees to three percent.

The in situ relative power of the six cell series string is shown in figure 6. After 6660 hours of illumination the series string degraded 23 percent. This degradation is in agreement with that of the three individual cells.

In table 2 the in situ degradation of the series string agrees with the control block data to within 2 percent.

Although the values are not shown on the figures, a comparison was made between the constant illumination results at 6660 hours and the cycling results at 6660 cycles (or hours of illumination). The average degradation of the September 1969 cells under constant illumination agreed to within 1 percent with the cycled June 1969 cells, but differed by 5 percent from that of the cycled November 1968 cells. It appears that the mode of illumination is less important than the vintage (manufactured date), if it has an effect at all.

TEMPERATURE DIFFICULTY

During the simulated orbital test some difficulties were encountered. One of the more important ones dealt with the temperature of the cells in chamber 1 changing during the test. At cycle 2229 the temperature of the cells was 12° C lower than at cycle 1.

Since the power output of a Cu_2S-CdS solar cell is a function of its temperature, it was necessary to determine whether this temperature change was real and why it was occurring. An investigation showed that this temperature change was real. It was the result of a redistribution of the solar simulator spectral irradiance which was caused by degradation of the solar simulator optics. In figure 7 the spectrum at the beginning of the test and at cycle 2229 are shown. These data indicate that the fraction of energy in the region where the Cu_2S-CdS standard cell is sensitive (0.5-1.0 μm) increased 13 percent. However, since a Cu_2S-CdS standard cell was used to set the simulator irradiance intensity, the total amount of energy input at the cell test plane was decreased 13 percent. This decrease was confirmed by radiometer measurements. Heat balance calculations indicate the resulting drop in temperature should be 12° C, as observed.

CONCLUDING REMARKS

The effect of long-term simulated space orbital testing on Cu_2S-CdS solar cells was evaluated. The thermal cycling test data presented here indicate that these cells degraded less severely in power output than cells tested earlier. The greater degradation is believed to be due primarily to excessive load voltage, although cell vintage may have been a contributing factor. In the earlier test the importance of load voltage was not recognized and the cells were probably loaded beyond the decomposition voltage of Cu_2S which resulted in greater degradation. In the recent thermal cycling test, cells were loaded at their initial maximum power voltage which is beyond the decomposition voltage of Cu_2S. The relatively slow degradation seen in the recent test is believed due to a different but yet unknown mechanism.

It appears that the mode of illumination (thermally cycled or continuously illuminated) has less of an effect on the degradation in cell power than the cell vintage, if it has an effect at all.

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Table 1 - Simulated Space Environmental Test of CdS Solar Cells

Thermal Cycling Test (Chamber-1)		Continuous Illumination Test (Chamber-2)	
No. of Cells	Manufactured	No. of Cells	Manufactured
4	Nov. '68	3	Sept. '69
5	June '69	Series String (6 cells)	Sept. '69

Table 2 - Individual Test Cell Characteristics

Cell No.	Manufactured	Efficiency 25° C, AMO	Degradation in Relative Power: In Situ Percent	Degradation in Relative Power: Control (1) Block Percent
1	Nov. 1968	3.4	24	25
2	Nov. 1968	3.2	19	19
3	Nov. 1968	3.0	9	15
4	Nov. 1968	3.2	18	21
5	June 1969	3.1	30	30
6	June 1969	3.2	31	33
7	June 1969	3.3	11	16
8	June 1969	3.6	16	22
9	June 1969	3.2	25	38
10	Sept. 1969	3.2	23	23
11	Sept. 1969	3.3	16	21
12	Sept. 1969	3.5	23	38
Series String	Sept. 1969	2.9	23	21

(1) Room air, 60° C, AMO

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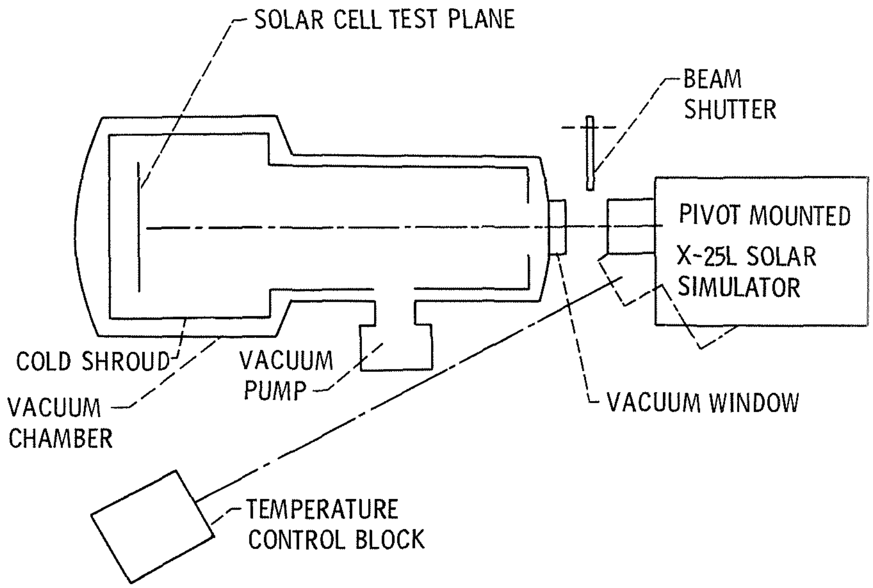

Figure 1. - Test facility - schematic.

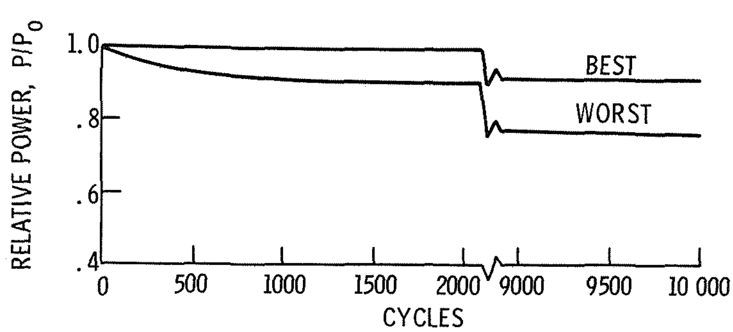

Figure 2. - Effect of thermal cycling on power output of November 1968 Cu_2S - CdS solar cells.

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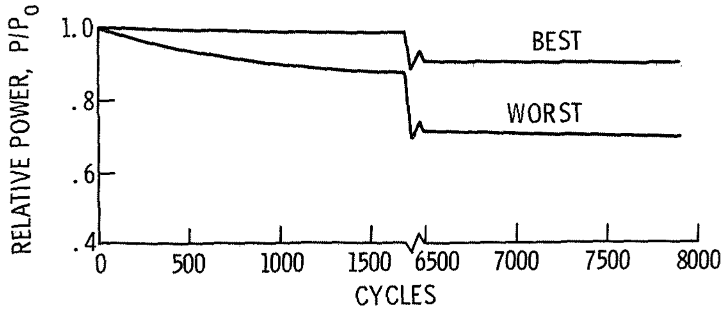

Figure 3. - Effect of thermal cycling on power output of June 1969 Cu_2S - CdS solar cells.

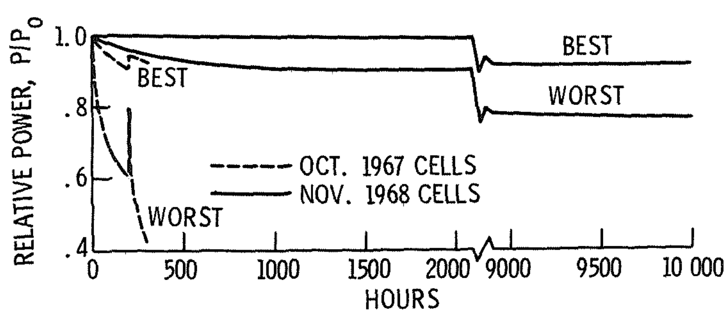

Figure 4. - Effect of thermal cycling on power output of October 1967 and November 1968 Cu_2S - CdS solar cells.

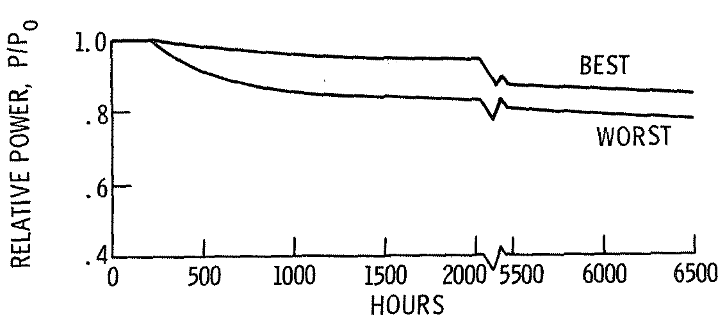

Figure 5. - Effect of continuous illumination on power output of individual September 1969 Cu_2S - CdS solar cells.

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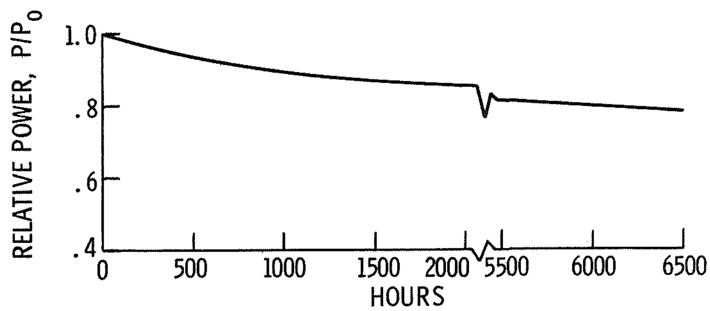

Figure 6. - Effect of continuous illumination on power output of September 1969 Cu_2S - CdS solar cell series string.

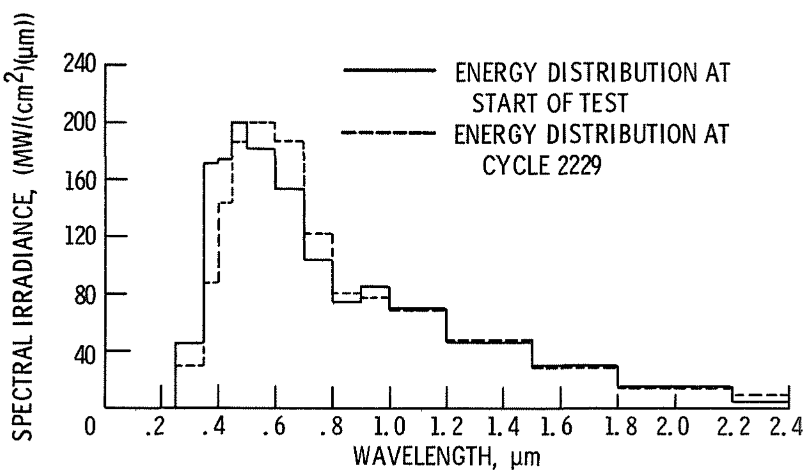

Figure 7. - Solar simulator energy distribution at start of test and at cycle 2229.